Diver-Portable Multi-Sensor Buried Mine-Hunter

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LONG-TERM GOALS

The long-term goal of this task is to identify and develop technology that will permit a diver to detect and localize fully buried mines as well as to detect, classify, and localize volume and partially buried mines.

OBJECTIVES

This task seeks to identify and develop technology that will permit a diver to detect and localize fully buried mines as well as to detect, classify, and localize volume and partially buried mines. This task seeks to develop a dual frequency, acoustic lens system with a lower frequency for buried target detection and a higher frequency for imaging/classification.

APPROACH

The approach to identify and develop the required technology for the diver-portable buried mine sensor system consists of five distinct efforts. In the first effort, an assessment of individual sensor technologies (electro-magnetics, electro-optics, and acoustics) was conducted to determine the most viable concept(s) for the sensor system. From this work, issues associated with candidate sensor concepts were identified and addressed in the second effort. A dual frequency, acoustic lens system was identified as a viable technology with lower frequency for buried target detection and higher frequency for imaging/classification of proud targets. Room temperature gradiometer was also identified as a viable technology. Laboratory testing was performed to address bottom penetration issues. Sea testing of a partially populated array was conducted to address trade-offs for buried target

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detection. A fully populated prototype system will be developed, and algorithms needed to process and display the signals will be developed. The prototype system will be tested, evaluated and demonstrated in a series of laboratory and sea tests.

In assessing the various sensor technologies, key issues needed to be considered in identifying candidate sensor concepts. For the acoustic sensors these issues included: (a) determine the effectiveness of a sonar (frequency, aperture size, beam pattern, pulse type, signal processing techniques, etc.) to detect completely buried mines and (b) identify and develop the technology required to develop an acoustic sensor(s) that will provide capability in classification. In the case of electromagnetic sensors, an important issue concerned: (c) the ability to detect and localize ferrous as well as non-ferrous mines. Whereas, the important technical challenges associated electro-optics include: (d) the clandestine mission requirement of Naval Special Warfare (NSW) forces and (e) high imaging resolution at extended ranges in turbid water conditions. Regardless of technology, the final issue that must be addressed is: (f) the integration and packaging of these sensors into a diver-portable unit.

In regard to issue (a), while there exists several sonar performance models such as SEARAY and the Shallow Water Acoustic Tool set (SWAT), which qualitatively predict sonar performance against volume and partially buried mines, no validated models exist that will accurately predict sonar performance against buried mines. The key modeling issue is to accurately predict the amount of acoustic energy that can propagate into sediment. Several experiments have measured higher acoustic penetration into sediment at shallow grazing than expected.[1,2] One proposed explanation for this anomalous penetration is the excitation of a biot slow wave in the sediment; here the porosity and permeability of the sediment are important factors.[3] A second proposed explanation is that increased penetration at shallow grazing angles may be possible if there exists a small level of roughness at the water-sediment interface.[4] In order to properly determine sonar tradeoffs (i.e., frequency, aperture size, beam pattern, etc.), an accurate accounting of bottom penetration capability needs to be incorporated into a sonar performance model. Therefore, a validated model that predicts sonar performance against buried targets is an open issue.

WORK COMPLETED

In FY 1996, a concept feasibility study for an appropriate diver-portable multi-sensor design was conducted in which various concepts employing electro-magnetics, electro-optics, and acoustics technologies were assessed. Results of this sensor technology assessment indicated that fusing a passive magnetic gradiometer sensor with a wide field-of-view (FOV), multiple-beam, dual-frequency (low frequency for buried mine detection and higher frequency for imaging/classification capability) acoustic lens sonar appears to offer the best possible capability for buried mine detection.[5] This study also identified issues associated with the candidate concepts. Since, Office of the Secretary of Defense (OSD) funded SBIR proposals are addressing concerns associated with the gradiometer, only acoustic issues are being addressed in this task. Important acoustic issues identified in this study included: (1) the lack of data associated with the material property (attenuation at frequencies less than 100 kHz and speed of sound) in candidate acoustic lens materials and (2) the mechanism for bottom penetration at shallow grazing angles has not been resolved. Thus, the SWAT sonar performance model is not validated against buried targets.

In FY 1997, efforts were performed, to resolve these acoustic issues. In the first effort, an experiment was conducted to obtain measurements of attenuation and speed of sound for ten different candidate

elastomeric materials. Data were acquired as a function of water temperature in the frequency range of 20 to 90 kHz. The ideal elastomeric material required for the lens design needs to possess a similar acoustic impedance to that of sea water (to reduce reflections from the lens material), act as a mask for the higher operating frequency while being almost acoustically transparent at the lower operating frequency, and possess a small variation in the temperature dependence of the speed of sound (thereby minimizing focusing problems). Elastomeric materials characterized included: various compositions of neoprene, EPDM, and nitrile as well as hypalon and silicone. Results of this effort indicated that EPDM 40D is a candidate material for the dual frequency lens design.

In the second effort, a laboratory experiment was performed to test if the roughness diffraction mechanism permits an increase in penetration at shallow grazing angles. This effort was initiated in FY 1997 and completed in FY 1998. In this experiment, two immiscible fluids (vegetable oil floating on glycerin) formed layers separated by an interface where small beads (polystyrene) were floated to simulate roughness. Hydrophones placed in the bottom layer (glycerin) were used to measure the acoustic levels transmitted across the interface. Data were acquired for three different bead diameters (6.35 mm, 4.763 mm, and 2.381 mm) and for various bead densities (densities of about 0.4, 0.8, and 1.6 beads/cm^2) at shallow grazing angles in the frequency range of 100 to 200 kHz. By conducting this measurement, the effects of surface roughness on propagation across this layer can be determined.

In FY 1998, candidate lens systems that were partially populated with acoustic elements were designed, fabricated, and assessed against buried targets in a measurement. This measurement was conducted in the last quarter of FY 1998 (September 7 - September 29), in the VSW region near the Army Corps of Engineers Field Research Facility in Duck, NC.[6] The objectives of this measurement were to: (1) assess the low frequency lens design and (2) obtain sonar performance data to determine tradeoffs on sonar parameters (frequency, aperture size, beam pattern, pulse type, etc.) for buried target detection, and (3) determine the coherence (a degree of match between two waveforms) of the transmitted waveform in a sandy bottom. Three distinct acoustic lens systems (12-inch, 10-inch, and 7.5-inch diameter apertures all of which operated in the frequency range of approximately 30 to 110 kHz) were assessed. These systems were attached to a stationary sonar tower complete with horizontal pan and vertical tilt motors. Calibrated retro-reflectors were used for the buried target detection portion of the measurement, and a buried hydrophone array was employed for the coherence measurements. Data were obtained as functions of frequency, pulse width, pulse type (i.e., short sinusoidal and broad band frequency modulated), sea state, and buried depth (retro-reflector and hydrophone array).

Future work includes the following four efforts. In the first effort, the data acquired during the FY 1998 testing will be analyzed to determine the sonar parameters required for buried target detection. Second, an effort will be conducted to determine the appropriate sonar parameters needed to obtain classification-type images. Third, using the results of the previous efforts, the dual frequency lens system will be designed. Fourth, the developed dual frequency, acoustic lens system will be fabricated and tested. Note, the motivation for the second task lies in the fact that previous measurements exploring the imaging capability of acoustic lens based sonar systems has been for either short range (less than 3 m), identification-type sonars operating in the 1 to 3.5 MHz frequency range[7-9] or ranges approaching 36 m in the 600 to 750 kHz frequency range with a 0.25° resolution;[10] the later system possesses a rudimentary imaging/classification capability.

RESULTS

Acoustic Propagation Across a Roughened Fluid-Fluid Interface

Results of the measurement corresponding to acoustic propagation across a roughened fluid-fluid interface have demonstrated an increase in the measured sound pressure levels when the beads were floated at the interface. The enhanced signal levels increased with increasing bead diameter and increasing bead density.[11,12] In addition, analysis of the data indicated that the roughness diffraction mechanism does yield an apparent slow sound speed (i.e., sound speed less than the fast compressional wave in the bottom layer). Furthermore, predictions of a simple model (developed under the Coastal Systems Station Independent Research Program) were found to yield qualitative agreement with data. This model assumed each bead to be a point scatterer and was used to calculate the apparent slow sound speed of the enhanced acoustic energy. While these results indicate that a non-flat sand bottom may cause an increase in transmitted acoustic energy into sediment at shallow grazing angles, these results do not eliminate the excitation of a biot slow wave in a sand-sediment as a possible mechanism.

Analysis of FY 1998 Data

The data collected in the FY 1998 testing are presently being analyzed. This analysis includes: (1) assessing the effectiveness of the lens design by determine any sources of internal reflections and by comparing the measured acoustic lens beam patterns to model predictions and (2) measuring the signal-to-noise ratio (SNR) of the buried calibrated retro-reflectors to determine optimal sonar parameters (e.g., frequency, beam width, and aperture size) for buried target detection.

IMPACT/APPLICATIONS

The sensors technologies developed under this task will be used to replace the Fleet AN/PQS-2A diver-portable sonar. The expected payoffs of the developed technology include: (a) a more reliable buried target detection capability than that of the AN/PQS-2A, (b) improved classification capability, (c) higher area coverage rates, (d) reduced mission execution times, and (e) a higher probability of mission success because of fewer missed detection opportunities.

TRANSITIONS

The diver-portable multi-sensor buried mine-hunter and test results as well as any developed detection, and classifier technology is being transitioned for further development under the Office of Naval Research’s (ONR) Surf Zone/Very Shallow Water core program. It is expected to eventually transition to either Program Management Office-Explosive Ordnance Disposal (PMS-EOD), the Very Shallow Water Mine Countermeasures (VSW MCM) Test Detachment or Special Operations Command (SOCOM) through either the Special Operations Special Technologies (SOST) program or the Explosive Ordnance Disposal/Low Intensity Conflict (EOD/LIC) program.

RELATED PROJECTS

1. The NSW Buried Mine Sensor task will monitor the efforts, utilize any applicable results, and exchange information to preclude any duplication of efforts in the following related projects.

2. An Advanced Motion Compensation for Synthetic Aperture Sonar (SAS) task funded by ONR

seeks to increase the area coverage rate of present SAS systems by developing sophisticated motion compensation algorithms.

3. The Direct Research Initiative (DRI) program “High-Frequency Sound Interaction in Ocean Sediments” is an ONR funded 6.1-type research effort which an objective to provide a physical understanding of the observed penetration into sediment at shallow grazing angles.

4. An acoustic lens effort, funded by ONR under an EOD program, is using acoustic lens techniques to develop a high resolution, short-range (less than 10 meters) imaging sonar which will operate at a frequency of 3 MHz.

5. The OSD sponsored SBIR effort Advanced, Man-Portable Locator of Magnetic Targets seeks to reduce the size, improve the temperature stability, and improve motion compensation capabilities of the present DIMMID prototype magnetic sensor.

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